Supplement to
NASA Technical Memorandum 81909

Support Interference of Wind Tunnel Models—A Selective Annotated Bibliography

Marie H. Tuttle and Pierce L. Lawing

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PREFACE

Support interference of wind tunnel models is a problem as old as wind tunnels themselves, and the lack of resolution of this problem has warranted a great deal of research into the magnitude and nature of the errors due to this interference. In NASA TM-81909, "Support Interference of Wind Tunnel Models — A Selective Annotated Bibliography," the 143 citations, from as early as 1923, document the severity of the problem.

Magnetic suspension and balance systems, or MSBS, covered in a recent bibliography (NASA TM-84661), have been considered a potential cure for many model support system problems for several decades. Although there have been sporadic applications of MSBS in many small wind tunnels, only recently have the technologies necessary to construct large wind tunnel systems become available.

The present supplement to NASA TM-81909 focuses on support interference problems thought to be directly solvable by MSBS. It includes both new citations and omissions very kindly brought to the authors' attention by users of NASA TM-81909. To preserve the focus of this supplement, documents dealing with computational corrections for the presence of the support on the model or on the tunnel wall influence have not been included, since these are not problems for which MSBS could be a solution, but rather are solutions to be used in the absence of an MSBS. Documents dealing with support interference at hypersonic speeds have not been included, since the facilities involved do not require a large-tunnel MSBS and the citations are so numerous as to merit a separate bibliography. Documents on flutter testing have been omitted, because at this time it is not clear that MSBS offer any improvement to the present flutter testing technique. Documents concerning exotic testing techniques used in both dynamic stability and two-body or stores separation testing have not been included, since MSBS are more likely to be used to remove support-related restrictions to this type of testing, and greatly improve the technique, rather than to correct errors due to the supports. Again, the large number of citations in this area suggests a separate bibliography.

The authors gratefully acknowledge the contribution of Colin P. Britcher, NRC Resident Research Associate at Langley Research Center, who provided important citations which were missing from the earlier work.

INTRODUCTION

The intent of this bibliographical supplement is to list publications that are not included in NASA TM-81909 and that pertain to support interference which would be eliminated by use of a magnetic balance and suspension system, or MSBS. Particular importance is assigned to citations dealing with large facilities and transonic flow. Since sting interference effects may be discussed in publications with no mention made of this fact in the title or abstract, omissions might occur. It is hoped that omissions of important documents will be called to the attention of the compilers, so that possible updated versions of or supplements to this bibliography may be more nearly complete and, therefore, more useful.

The entries in this supplement continue the numbering begun in the original publication and run from 144 through 176. The arrangement is chronological by date of publication. However, papers presented at conferences or meetings are placed under dates of presentation.

Most of the abstracts used are from the NASA announcement bulletins, "Scientific and Technical Aerospace Reports" (STAR) and "International Aerospace Abstracts (IAA). In some other cases authors' abstracts were used. License was taken to write, shorten, or otherwise modify abstracts.

The author index at the back of this supplement covers both the original bibliography (NASA TM-81909) and this supplement.

If it is known that a paper has appeared in several forms, mention is made of this fact. When available, accession numbers, report numbers, and other identifying information are included in the citations in order to facilitate the filling of requests for specific items. When requesting material from your library or other source, it is advisable to include the complete citation, omitting the abstract. A "#" after an acquisition number indicates that the document is also available in microfiche form.

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AD Numbers	Report literature with or without distribution limitation	Defense Technical Information Center Cameron Station Alexandria, VA 22314

For any other type of material, contact your library or the NASA Scientific and Technical Information Facility (see address above), and include any information given.

144 *Hummel, D.: **Untersuchungen über das Aufplatzen der Wirbel an Schlanken Deltaflügen (Investigations of Vortex Breakdown on Slender Delta Wings).** Presented at a joint meeting of NGLR and OGRR, Berlin, Sept. 14–18, 1964. Also Zeitschrift für Flugwissenschaften, vol. 13, May 1965, pp. 158–178 (in German).

A65-26140 (paper)
A64-26699 (journal article)

English translation published as ARA-LIB-TRANS-12,
Aircraft Research Assoc., Oct. 1965, 23 pp.

N66-15581#

The results of experimental investigations on vortex breakdown on slender delta wings at low speed are presented. The phenomenon of vortex breakdown has been investigated by measuring the flow field over a delta wing with aspect ratio of 0.78. The results are compared with the stability theory after H. Ludwieg. In order to determine the effect of vortex breakdown on the aerodynamic characteristics of a wing, six component measurements and pressure-distribution measurements on a delta wing with aspect ratio of 1.0 have been carried out. The forces and moments decrease when the vortices break down just above the wing. These experiments show the large effect of support interference on the shed vortices which then changes the wing loading.

*Deutsche Forschungsanstalt für Luft- und Raumfahrt, Institut für Aerodynamik, Braunschweig, West Germany.

145 *Horton, V.W.; *Eldredge, R.C.; and *Klein, R.E.: **Flight-Determined Low-Speed Lift and Drag Characteristics of the Lightweight M2-F1 Lifting Body.** NASA TN-D-3021, Sept. 1965, 44 pp.

N65-33357

The low-speed lift and drag characteristics of a manned, lightweight M-2 lifting-body vehicle were determined in unpowered free-flight tests at angles of attack from 0° to 22° (0.38 radian) and at calibrated airspeeds from 61 knots to 113 knots (31.38 to 58.13 meters/second). Flight data are compared with results from full-scale wind-tunnel tests of the same vehicle. The investigation showed that 95 percent of the vehicle maximum lift-drag ratio of 2.8 was available through an angle-of-attack range from 4.4° to 14.6° (0.08 to 0.25 radian). Although this lift-drag ratio is considered low in comparison with most other aircraft, no serious difficulties were experienced in landing the test vehicle. Although the same vehicle was tested in flight and in the wind tunnel, significant differences existed in the values of zero-lift drag and drag due to lift. There were no model problems because the real vehicle was used in the tunnel tests. The Reynolds number and Mach number were close to flight. The angle of attack was small enough not to present wall interference problems, and there were no propulsion system effects because there was no propulsion system. That leaves support interference or poor flow quality to account for the differences. Measured zero-lift drag was over 15% higher in the tunnel.

*NASA, Flight Research Center, Edwards, CA 93523

146 *Ongarato, J.R.: **Trisonic Wind Tunnel Studies to Investigate Tunnel Wall Interference and Sector Support Effects at Subsonic and High Subsonic Mach Numbers.** NA-66-322, Aug. 18, 1966, 53 pp.

N69-72323

The data presented in this report were obtained from tests of two wind tunnel force models, one being a Douglas Aircraft Company model and the other a 0.06 scale representation of the NAA Short Range Transport. From an analysis of the data presented, the following conclusions pertinent to this bibliography were made. The drag levels of these models are not appreciably affected by the sector support if model base to leading edge of sector distance is 60 inches or more and only affected slightly more when this distance is between 48 and 60 inches. Further streamlining of a standard TWT sting and sector head configuration will not reduce the effect of the sector support on wind tunnel models of moderate size.

*North American Aviation, Inc., Los Angeles, CA.

147 *Soulier, C.: **Measurements in a Wind-Tunnel of the Drag of the Rear Parts of Aircraft Models.** ONERA-TP-633, 1968, 7 pp. Presented at the 30th Supersonic Tunnel Association Meeting, Columbus, Ohio, Oct. 3–4, 1968.

A69-11624#

A wind-tunnel method is described for measuring the drag on the rear parts of small-scale aircraft models with the aid of an internal dynamometer and an inflatable membrane made of reinforced elastomer. The membrane was found to function smoothly in 60-run supersonic tests yielding results accurate to within less than 0.85%. The method is presently being used in the transonic range in a continuous wind tunnel with good results.

*ONERA, 92320 Châtillon, France

148 *Taylor, C.R.; *Hall, J.R.; and *Hayward, R.W.: **Super VC 10 Cruise Drag—A Wind-Tunnel Investigation. Part 1, Experimental Techniques.** British ARC CP–1125, Aug. 1969, 44 pp.

N71-17118#

Measurements have been made of the longitudinal forces and moments on a 1/27 scale model of the Super VC 10 at Mach numbers between 0.60 and 0.86. This report gives details of the model design, the test techniques, and the corrections applied. It includes a critical assessment of measuring techniques used. The main purpose of the work was to produce accurate drag information for a realistic aerodynamic representation of the aircraft at the highest practical Reynolds number. The measurements were compared with flight data. Basic single-sting tests were made at a unit Reynolds number of 6×10^6 per foot, or Reynolds number based on the mean geometric chord of 4.45×10^6. The model was tested both erect and inverted in steps of 0.15 degrees. Tests were made to measure the single-sting interference (using a twin-sting support). Results from these tests are given and discussed. A complete set of derived support corrections is given.

*Aerodynamics Dept., R.A.E., Bedford, England

149 *Saltzman, E.J.; and *Bellman, D.R.: **A Comparison of Some Aerodynamic Drag Factors as Determined in Full-Scale Flight With Wind-Tunnel and Theoretical Results.** NASA TM X-67413, Aug. 1971, 9 pp. Presented at the Fluid Dynamics Panel Specialists' Meeting, Göttingen, Germany, Apr. 27–28, 1971. Paper no. 16 in "Facilities and Techniques for Aerodynamic Testing at Transonic Speeds and High Reynolds Number,"AGARD CP-83-71 (N72-11854), Aug. 1971, 22 pp.

N72-11869#

Reliable techniques for defining flight values of overall aircraft drag and turbulent skin friction and the drag associated with local regions of separated flow are reported. Selected results from these studies are presented for several types of aircraft, including the X-15, the XB-70, lifting bodies, and military interceptors. These flight results are compared with predictions derived from wind-tunnel models or, for friction, with the Karman-Schoenherr relationship. The flight experiments have defined the turbulent skin friction to Reynolds numbers somewhat above 10^8, the overall drag of two airplanes, base pressure coefficients for aircraft and for an aft-facing step immersed in a thick boundary layer. A flight application of a splitter plate for reducing base drag is discussed along with examples of the drag associated with afterbody flow separation for shapes having relatively large afterbody closure angles. Evidence con-

firmed that sting and strut supports were among the major barriers to adequate simulation of drag.

* NASA, Flight Research Center, Edwards, CA 93523

150 *Simper, J.I.; and *Hutton, P.G.: **Results of a Series of Wind Tunnel Model Breakdown Tests on the Trident 1 Aircraft and a Comparison With Drag Estimates and Full Scale Flight Data.** British ARC CP-1170, 1971, 84 pp.(Supersedes ARC 32252 and ARA Rept. no. 14.)

N72-15974#

Four configurations were tested on two different sting support systems. These systems, and the model modifications necessary to test on these systems, are discussed. Due to the presence of the support sting in simple sting tests, the measured model lift, drag, and pitching moment included some interference effects. By comparing results obtained from two sets of twin sting configurations, values of the sting interference were derived and corrections were applied to the single sting test results.

*Aircraft Research Association, Ltd, Manton Lane, Bedford MK41 7PF, U.K.

151 *August, H: **B-1 Airplane Model Support and Jet Plume Effects on Aerodynamic Characteristics.** Presented at the AIAA 11th Aerospace Science Meeting, Washington, D.C., Jan. 10–12, 1973, 5 pp.

AIAA Paper 73-153 A73-16901#

Wind-tunnel test programs designed to provide more representative flow-field simulation have been performed. Influence of afterbody closure and jet plume interference on lift, drag, longitudinal and directional static stability, and control surface effectiveness has been determined. These incremental data were measured by a force and moment balance installed in the aft fuselage of a strut-supported, complete configuration model. These data are applied to force model test results of a typical sting-supported, ducted nacelle configuration. In this manner, representative B-1 airplane aerodynamic characteristics at trimmed flight conditions have been determined.

*Rockwell Aircraft Corp., 815 Lapham St., El Segundo, CA 90245

152 *Binion, T.W.: **Special Wind Tunnel Test Techniques Used at the AEDC.** Presented at the 46th Meeting of the Flight Mechanics Panel, Valloire, France, June 9–13, 1975. Paper no.3 in "Flight/Ground Testing Facilities Correlation," AGARD CP-187 (N76-25266#), Apr. 1976, 13 pp.

N76-25270#

This paper discusses test techniques to satisfy testing requirements for (1) captive loadings and trajectories of external stores, (2) maneuver and departure characteristics of aircraft, and (3) static stability characteristics of missiles at angles of attack up to 180°. Charts show slender body supports for testing at very high incidence, effect of Reynolds number on normal force with both sting and strut supports with an ogive cylinder model and a comparison of support techniques.

*ARO, Inc., Arnold Engineering Development Center, Arnold Air Force Station, TN 37389

153 *Aulehla, F.: **Drag Measurement in Transonic Wind Tunnels.** Presented at the Flight Mechanics Panel Specialists' Meeting on "Performance Prediction Methods," Paris, Oct. 11–13, 1977. Paper no. 7 in AGARD CP-242 (N78-26074), May 1978, 18 pp.

N78-26080#

In order to increase accuracy taking into account the simultaneously measured wall pressure is recommended. By linking these wall pressures with theoretical wall interference computations, it seems possible to approach the absolute limit of accuracy. This requires, however, consideration of axial pressure gradients produced by the tunnel wall or by inappropriate model suspensions. An example shows that these pressure gradients can cause errors in the absolute pressure drag of more than 100% and even in the drag differences of about 20%. The influence of Reynolds number on afterbody drag and on wing shock locations is critically reviewed and the variation of wind tunnel boundary layer is suggested as the prime cause for these effects. Lastly, unsteady flow separation problems are briefly discussed and general recommendations for improved drag assessment are made. Interference from model supports is also discussed.

*Messerschmidt-Boelkow G.m.b.H., Munich, West Germany Unternehmensbereich Flugzeuge

154 *Simpson, A.; and *Flower, J.W.: **Unsteady Aerodynamics of Oscillating Containers and Application to the Problem of Dynamic Stability of Helicopter Underslung Loads.** Presented at the Fluid Dynamics Panel Symposium, Athens, Greece, May 22–24, 1978. Paper no. 13 in "Dynamic Stability Parameters," AGARD CP-235 (N79-15061), Nov. 1978, 33 pp.

N79-15073#

Loads slung beneath helicopters can develop alarming oscillations at quite low airspeeds, due to aerodynamic forces, and hence severely curtail the performance of the helicopter. The investigation highlights the (sometimes overriding) importance of load movement on the aerodynamic forces for the particular case of the standard $20 \times 8 \times 8$ foot container. Because of their nonaerodynamic shape the containers experienced separated flow even at very low speeds. Consequently, the aerodynamic characteristics were very nonlinear and associated with aerodynamic hysteresis. As a result, one degree of freedom limit cycle oscillations, of stall flutter type were observed. Quasi-steady methods could not be used in the analysis because of the high reduced frequency associated with the low forward speed. (This is also the case when analyzing dynamic stall and associated stall flutter of the helicopter blades.) The paper also showed an example of strong support interference. It occurred when the clumsy strut structure, supporting the sting, was too close to the model.

*Dept. of Aeronautical Engineering, Univ. of Bristol, Bristol, BS8 1TH, England

155 *Brännström, B. and *Lindau, O.: **Investigation of Interference Effects in a Wind Tunnel From a Model Support Strut on a Reflection-Plane Mounted Half Model.** The Aeronautical Research Institute of Sweden (FFA), TN-FFA-AU-1335, 1978, 95 pp.

N79-27109#

This work was carried out as a final-year project for a M.S. Thesis, Royal Institute of Technology, Stockholm, Sweden, 1978.

A theoretical and experimental investigation of the interference effects in a wind tunnel of the support strut for complete models on the flow around a reflection-plane mounted half-model has been made at FFA. The theoretical part consisted of a computer simulation of the flow around a half-model in the wind tunnel with and without the support strut. The experimental part consisted of wind tunnel tests with a 1:25 scale model in the $0.5 \times 0.5 m^2$ transonic wind tunnel S5 at Mach numbers from 0.5 to 0.975. Three different struts were investigated. The theoretical estimates of the interference loads at small incidence agree well with the measured values. The effects are in general small except at higher angles of attack where the effects increase. This is especially noticeable in the pitching moment, as a result of which the pitch-up occurs earlier.

*Aeronautical Research Institute of Sweden, Stockholm, Sweden

156 *Price, E.A., Jr.: **An investigation of F-16 Nozzle-Afterbody Forces at Transonic Mach Numbers With Emphasis on Support System Interference — Final Rep., Jan.–July, 1978.** AEDC-TR-79-56; AFAPL-TR-79-2099; Dec. 1979, 207 pp.

AD-A078693 N80-18046#

A comprehensive experimental program was conducted to provide nozzle-afterbody data with a minimum interference support system on a 1/9-scale F-16 model and to determine the interference induced on the afterbody-nozzle region by a sting, a wing tip and a strut model support system. The investigation was conducted over the Mach number range from 0.6 to 1.5 and at angles of attack from 0 to 9 deg. Interference was evaluated by comparison of nozzle-afterbody axial and normal forces obtained from integrating pressure data. The results include parametric studies of the effects of various components of the wing tip support system (i.e., the support blade axial position, wing tip boom diameter, boom spacing, and boom-tip axial location). High-pressure air at ambient temperature was utilized for exhaust plume simulation. The results indicate that sting support passing through the nozzle with the jet effects simulated by an annular jet appears to offer a minimum interference support system for the type of nozzle-afterbody test described in the report.

*ARO, Inc., Arnold Air Force Station, TN 37389

157 *Ericsson, L.E.; and *Reding, J.P.: **Vortex-Induced Asymmetric Loads in 2-D and 3-D Flows.** Presented at the AIAA 18th Aerospace Sciences Meeting, Pasadena, California, Jan. 14–16, 1980, 46 pp., 136 refs.

AIAA Paper 80-0181 A80-19290#

The steady and unsteady vortex-induced loads on slender vehicles have been investigated. The study consisted of a review of pertinent two-dimensional and three-dimensional data, the development of analytic means for prediction of the upper limit for vortex-induced asymmetric loads, and the assessment of the importance of these loads to the vehicle dynamics of slender bodies of revolution. Boundary layer transition was found to have a dominant influence on static and dynamic vortex-induced loads. The predicted upper limit for vortex-induced asymmetric loads bounds all available experimental results from subcritical to super-critical Reynolds numbers. The most powerful dynamic effect is that of the moving wall at the separation point, which has a wall-jet-like effect on the boundary layer transition and separation. The study showed that the poor capability of existing theory to predict the vortex-induced asymmetric loads is most likely due to the neglect of the dominating role played by a pointed, slender nose. Although much research still remains to be done before we will have a complete understanding of the generative processes leading to asymmetric vortices on slender, pointed bodies of revolution, the intensity and variety of present efforts indicates that this goal will be reached in a not too distant future.

*Lockheed Missiles & Space Co., Sunnyvale, CA 94086
Contract N609177 C-0234

158 *Johnson, J.L., Jr.; *Grafton, S.B.; and *Yip, L.P.: **Exploratory Investigation of the Effects of Vortex Bursting on the High Angle-of-Attack Lateral-Directional Stability Characteristics of Highly-Swept Wings.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colorado, Mar. 18–20, 1980. In AIAA Technical Papers, 1980, pp. 282–297.

AIAA Paper 80-0463 A80-26960#

A recent low-speed wind-tunnel investigation of highly swept wings has shown that the vortex breakdown at high angles of attack can cause large destabilizing effects on static lateral-directional stability characteristics and that the destabilizing effects of vortex breakdown can be greatly aggravated by model support strut interference effects. The present paper discusses these effects based on the results of static force tests of several highly swept wing configurations for different wind-tunnel strut arrangements. Also included in the paper are photographs obtained during tuft-, smoke-, and helium-bubble flow visualization studies to indicate wing flow behavior patterns.

*NASA, Langley Research Center, Hampton, VA 23665

159 *Ericsson, L.E.; and *Reding, J.P.: **Transonic Sting Interference,** Journal of Spacecraft and Rockets, vol. 17, Mar.–Apr., 1980, pp. 140–144, 19 refs.

AIAA Paper 79-0109 A79-19536#

Note: See No. 133 in this bibliography (NASA TM-81909) for an earlier form of this paper.

One of the problems that has to be solved in order to improve the accuracy of the results obtained in ground facilities is that of support interference, especially in regard to dynamic test data. While the dynamic sting interference has been well documented for hypersonic flow, it is generally only expected at transonic speeds in the cases where the body has a bulbous, dome-shaped base or a boattail. However, it is shown in the present paper that when boundary-layer transition occurs on the aft body, sting interference becomes a problem for all body geometries.

*Lockheed Missiles & Space Co., Inc., Sunnyvale, CA 94086

160 *Vaucheret, X.: **Améliorations Envisagées pour Résoudre les Problèms Rencountrés au Cours d' Essais à Grande Incidence de Maquettes en Soufflerie (Expected Improvements on High Angle of Attack Model Testing).** ONERA TP-1980-36. Presented at an AGARD Fluid Dynamics Panel Round Table Discussion, Munich, Germany May 8,1980. Paper No. 3 in "Wind Tunnel Corrections for High Angle of Attack Models," AGARD R-692. (N81-24120), Feb. 1981, 22 pp. (in French).

A80-40804 (ONERA report)
N81-24123 (AGARD paper)

Problems encountered during tests at high angle of attack in wind tunnels are wall interference, sting interference, and vibrations beyond the stall. The state of the art on wall interference systematically applied to the development tests is shown with several comparisons between tests in different wind tunnels or between flight and tunnel tests. The models used in unconfined flow point out some deficiencies as regards apex vortex and active jets. The control of the validity of the wall interference correction method is analyzed. Line drawings and graphs show the effect of the supports on drag. There are 18 references.

*ONERA, 92320 Châtillon, France

161 *Nyberg, S.E.: **A Review of Some Investigations on Wind Tunnel Wall Interference Carried out in Sweden in Recent Years.** Presented at an AGARD Fluid Dynamics Panel Round Table Discussion, Munich, Germany, May 8, 1980. Paper No. 6 in "Wind Tunnel Corrections for High Angle of Attack Models," AGARD R-692 (N81-24120), Feb. 1981, 9 pp.

N81-24126#

For subsonic incompressible flow the mutual circulation-induced model wind tunnel interference was calculated by panel methods for large multicomponent two-dimensional airfoils, for three-dimensional swept wings, full- or half-models, and for wing-tail configurations. Wake blockage effects from a swept wing with and without high lift devices were studied experimentally. The effects of air flow leakage between the half-model fuselage and the reflection wall were investigated. For transonic flow the flow properties of slotted walls and the influence of wall boundary layer were studied. Based on these results a numerical method was developed and axisymmetric calculations were carried out. The results were compared with experimental results for large blockage models. A bibliography of 16 documents is included.

*Aeronautical Research Institute of Sweden, Bromma, Sweden

162 *Price, E.A., Jr.: **Interference on a Model Afterbody From Downstream Support Hardware at Transonic Mach Numbers — Final Rep., 27 June – 2 July, 1979.** AEDC-TR-80-27, Jan. 1981, 51 pp.

AD-A093739 N81-16981#

An experimental program was conducted to parametrically study the interference on an afterbody model that would be produced by the aft support blade used with a wing-tip support system. Geometric variables included the blade axial location, thickness, span, chord, and leading and trailing edge contours. Data were obtained over the Mach number range from 0.6 to 1.2 with the model at zero angle of attack. Interference was evaluated by comparing afterbody drag from a reference configuration, which had the aft support blade removed, to the various configurations with a blade installed. A reasonable correlation of the blade interference effects on the afterbody drag coefficient was obtained, which included the influence of support blade axial position and blockage. Decreasing blade leading edge bluntness by a factor of two resulted in a significant reduction of interference in the Mach number range from 0.9 to 1.1. Significantly greater interference was measured without jet flow than with jet flow. It is shown that a Euler equation computer code is a useful tool for the design of minimum interference support systems.

*ARO, Inc., Arnold Air Force Station, TN 37389
Sponsored by the U.S. Air Force

163 *Price, E.A., Jr.; and **Glidewell, R.J.: **Reynolds Number and Model Scale Effects on F-16 Nozzle-Afterbody Forces.** Presented at the AIAA, SAE, and ASME 17th Joint Propulsion Conference, Colorado Springs, Colorado, July 27–29, 1981, 14 pp.

AIAA Paper 81-1442 A81-40876#

A series of wind tunnel tests was conducted in the Arnold Engineering Development Center 16-ft transonic wind tunnel. These tests utilized both a 0.11 - and a 0.25-scale F-16 nozzle-afterbody model. During the tests, Mach number, Reynolds number, angle of attack, nozzle pressure ratio, and horizontal tail deflection were varied. Data are presented for sting-supported versions of each model to demonstrate variations in throttle-dependent, nozzle-afterbody pressure drag resulting from changes in Reynolds number, model scale, and other test variables. The paper also presents a comparison of the support system interference effects resulting from a strut support system on the two scale models. Results indicate good agreement between the two scale models at subsonic Mach numbers when they are sting supported. Very little effect of Reynolds number was evident throughout the tests. Wave interference effects produce measurable differences in the data for Mach numbers between 0.95 and 1.5. Significant differences in strut interference were measured on the two scale models, particularly at Mach numbers from 0.95 to 1.2.

*Arvin/Calspan Field Services, Inc., Arnold Air Force Station, TN 37389

**USAF, Aero Propulsion Lab., Wright-Patterson AFB, OH 45433

164 *Cyran, F.B.: **Sting Interference Effects on the Static Dynamic and Base Pressure Measurements of the Standard Dynamics Model Aircraft at Mach Numbers 0.3 Through 1.3 — Final Rep. June–Dec. 1980.** AEDC-TR-81-3, Aug. 1981, 66 pp.

AD-A102612 N81-32124#

Wind tunnel tests were conducted in the Arnold Engineering Development Center (AEDC) Propulsion Wind Tunnel Facility (PWT) to provide sting-support interference information for planning and directing wind tunnel tests at subsonic and transonic Mach numbers. Sting length and diameter effects on static and dynamic stability derivatives, static pitching moments, and base pressure of the Standard Dynamics Model (SDM) were investigated at Mach numbers from 0.3 to 1.3. Dynamic stability derivatives were obtained at a nominal frequency of 5.2 Hz, at amplitudes of 1.0, 1.5, and 2.0 deg. Pitch and yaw data were both obtained as a function of angle of attack. Previously unpublished static force and moment data for the SDM are also presented. The results showed the interference related to sting length was most pronounced at Mach 0.95 for all measurements; the results also showed significant effects at Mach 1.1 and 1.3 for yaw damping. Substantial sting diameter effects were observed at Mach 0.3 for pitch damping and at Mach 1.3 for yaw damping. Both sting length and diameter effects were found in base-pressure measurements at most Mach numbers.

*ARO, Inc., Arnold Air Force Station, TN 37389
Sponsored by the U.S. Air Force

165 *Conine, B.; and *Boyle, W.: **Space Shuttle Solid Rocket Booster Sting Interference Wind Tunnel Test Analysis — Final Rep.**NASA-CR-161885; TR-230-2042; Sept. 15, 1981, 235 pp.

N82-11040#

Note: For the appendix to this report, see no. 170 in this bibliography.

Wind tunnel test results from shuttle solid rocket booster (SRB) sting interference tests were evaluated, yielding the general influence of the sting on the normal force and pitching moment coefficients and the side force and yawing moment coefficients. The procedures developed to determine the sting interference, the development of the corrected aerodynamic data, and the development of a new SRB aerodynamic mathematical model are documented.

*Northrop Services, Inc., Huntsville, AL 35812
Contract NAS8-33816

166 *Ericsson, L.E.; and *Reding, J.P.: **Support Interference in Static and Dynamic Tests.** Presented at the International Congress on Instrumentation in Aerospace Simulation Facilities, Dayton, Ohio, Sept. 30, 1981. In ICIASF '81 Record (A83-11051), Inst. Electrical and Electronic Engineers, Inc., 1981, pp. 213–223, 18 refs.

A83-11074

The existing information about support interference has been reviewed, with particular emphasis on dynamic interference effect and the special problems encountered at high angles of attack. It is found that support interference effects are much more severe in dynamic than in static tests. Furthermore, the support interference is aggravated greatly by a boat-tail or dome-shaped base, even by modest base shoulder roundness, from what it is for a flat-based model. The general conclusion is that asymmetric stings or sting-strut combinations should be avoided.

*Lockheed Missiles & Space Co., Inc., Sunnyvale, CA 94086

167 *Lynch, F.T.; and *Patel, D.R.: **Some Important New Instrumentation Needs and Testing Procedure Requirements for Testing in a Cryogenic Wind Tunnel Such as the NTF.** Presented at the AIAA 12th Aerodynamic Testing Conference, Williamsburg, Virginia, Mar. 21–24, 1982, 13 pp.

AIAA Paper 82-0605

To exploit the potential advantage of the very high Reynolds number capability that will be provided by the NTF, several issues regarding instrumentation requirements and testing techniques must be addressed. The third major issue discussed in this paper deals with model support system interference effects. We show that determination of these effects is of even greater concern in the NTF than it is in current transonic wind tunnels. To shed some light on the magnitude of the potential sting interference effects, a wind-tunnel test was conducted by Douglas with a DC-10 model utilizing a sting configuration very similar to the NTF sized design. It is very clear that the interference effects attributable to the larger sting sizes required to achieve full-scale Reynolds numbers on models in the NTF must be accounted for. The capability to provide alternate model sting configurations and means for supporting dummy-sting installations at the high dynamic pressures to be encountered in the NTF must be developed so that sting interference effects can be routinely evaluated for typical three-dimensional model configurations.

*Douglas Aircraft Co., McDonnell Douglas Corp., Long Beach, CA 90846

168 *Vaucheret, X: **Wall Interference Correction Improvements for the ONERA Main Wind Tunnels.** Presented at Fluid Dynamics Panel Specialists' Meeting, London, May 19–20, 1982. Paper no. 11 in "Wall Interference in Wind Tunnels," AGARD CP-335 (N83-20957#), Sept. 1982 (in French).

N83-20968#

Translation by Kanner (Leo) Associates, Redwood City, California. NASA TM-76971, Aug. 1982, 24 pp.

N83-33908#

Describes improved methods of calculating wall interference corrections for the large ONERA wind tunnels. The mathematical description of the model and its sting support have become more sophisticated. An increasing number of singularities are used until agreement between theoretical and experimental signatures of the model and sting on the walls of the closed test section is obtained. The singularity decentering effects are calculated when the model reaches large angles of attack. The porosity factor cartography on the perforated walls deduced from the measured signatures now replaces the reference tests previously carried out in larger tunnels. The porosity factors obtained from the blockage terms (signatures at zero lift) and from the lift terms are in good agreement. In each case (model + sting + test section), wall corrections are now determined, before the tests, as a function of the fundamental parameters *M, CS, CZ.* During the wind-tunnel tests, the corrections are quickly computed from these functions.

*ONERA, 92320 Châtillon, France
Contract NASW-3541

169 *Uselton, B.L.; and *Haberman, D.R.: **Summary of Sting Interference Effects for Cone, Missile, and Aircraft Configurations as Determined by Dynamic and Static Measurements.** Presented at the 9th AIAA Atmospheric Flight Mechanics Conference, San Diego, California, Aug. 9–11, 1982, 16 pp., 21 refs.

AIAA Paper 82-1366 A82-40395#

A summary of an AEDC technology program of sting effects on aerodynamic measurements is presented. Four different configurations — a 7-deg cone, 6-deg sliced-base cone, missile, and an aircraft — were tested in the wind tunnel. Interference effects were obtained by measurements of damping derivatives, static data, surface pressures, and base pressures from subsonic to hypersonic Mach numbers. The critical sting limits were investigated as a function of frequency of oscillation, model boundary layer, type of measurement, angle of attack, Mach number, and configuration. Comparisons of wind tunnel and ballistic range data are presented for the missile and aircraft configurations. Critical sting length was found to depend on the parameter selected as the interference indicator.

*Calspan Field Services, Inc., Arnold Air Force Station, TN 37389

170 *Conine, B.; and *Boyle, W.: **Solid Rocket Booster Sting Interference Wind Tunnel Test Analysis, Appendix D.** NASA-CR-162084; NAS 1.26.162082; TR-230-2042-A; Aug. 1982, 221 pp.

N82-32311#

Note: For the main report, see no. 165 in this bibliography.

Additional analyses of wind tunnel test results from SRB sting interference test TWT 660 and HRWT 042 were conducted to evaluate the sting interference that may be present in the Space Shuttle SRB reentry aerodynamic math model. Additional wind tunnel data were obtained at higher angles of attack from test program TWT 660 and test program HRWT 042. The additional data were analyzed to evaluate the procedures used to fair the data in the development of the SRB reentry aerodynamic data Tape. no. 5.

*Northrop Services, Inc., Huntsville, AL 35812
Contract NAS8-33816

171 *Binion, T.W.; **Vaucheret, X.; and **Bouis, X.: **Progress in Wind Tunnel Test Techniques and in the Corrections and Analysis of the Results.** Presented as paper No. 2 at the 61st AGARD Meeting, Cesme, Turkey, Oct. 11–14, 1982. ONERA TP No. 1982-108, 32 pp. 23 refs.

A83-18434#

A general overview is presented of some of the innovations devised for the improvement of the effectiveness of wind tunnel testing. Efforts have centered around three approaches: (1) increasing the amount of information, as opposed to data, that can be obtained in ground test facilities, (2) reducing test costs per data unit, and (3) improving data quality. Areas in which innovations have been realized include propulsion system simulations aimed at reducing drag in transport aircraft, and engine-airframe integration in combat aircraft. Cost reduction may be achieved by computer-controlled constant parameter testing and parameter optimization, stereophotographic techniques and computerized store trajectory generation in the captive trajectory system. Improvements in instrumentation have concerned store alignment, the application of an electro-optical interferometer, and airflow intake transducers. Developments in micro- and mini-computers have led to automated test control, data acquisition, and measurement device checking. Finally, advances have been made in the long-term repeatability of test data, corrections for sting and wall interference, and the comparison of test data obtained at different installations.

*Calspan Field Services, Inc., Arnold Air Force Station, TN 37389
**ONERA 92320, Châtillon, France

172 *Gloss, B.B.; and *Sewall, W.G.: **Support-Sting Interference on Boattail Pressure Drag for Reynolds Numbers up to 70 x 10^6.** Presented at AIAA 21st Aerospace Sciences Meeting, Reno, Nevada, Jan. 10–13, 1983. 11 pp.

AIAA Paper 83-0387 A83-16687#

A model was tested in the Langley 0.3-Meter Transonic Cryogenic Tunnel to investigate the effects of Reynolds number on boattail pressure drag for a variety of sting shapes. The boattail pressure drag for constant Mach number increased linearly with Reynolds number over the Reynolds number range tested. The data indicated that as the disturbance produced by the sting on the boattail increased, the boattail pressure drag became less sensitive to Reynolds number change. Also, it was found that the model base pressure versus Reynolds number curve reached a plateau within the Reynolds number range examined.

*NASA, Langley Research Center, Hampton, VA 23665

173 *Rebuffet, P.: **The Effects of Supports on the Flow Behind a Body.** NASA TM-77073, May 1983, 43 pp.

N83-33909

Note: This is a translation by Kanner (Leo) Associates, Redwood City, California of a paper presented at La Reunion sur les Effets des Interactions en Soufflerie du Groupe de Travail AGARD Dynamique Des Fluides, Rhode St. Genese, Belgium, Mar. 2–5, 1959. NATO Rep. 302 (N80-71569#), 1959, pp. 1–31.

Two cases in a supersonic flow with a turbulent boundary layer are studied in order to determine the effects of supports on models with a flat base. The first concerns the effect of various obstacles situated upstream of the two-dimensional base, at Mach 2. The second relates to a body of revolution passing through the throat of the jet from upstream to downstream. The interference of obstacles simulating supporting masts is examined for the base, both bare and with a sting, at Mach 1.94. Without any support, the drag of a conical-cylindrical body of revolution was measured by means of the ONERA magnetic suspension. The interference of various stings was studied at Mach 2.4 with a laminar boundary layer and with a separated turbulent boundary layer. The mechanism

of the interference of a sting, progressively approached axially to the base, was determined.

*NATO, Rue de Varenne, Paris, France

174 *Tuttle, M.H.; **Kilgore, R.A.; and **Boyden, R.P.: **Magnetic Suspension and Balance Systems — A Selected, Annotated Bibliography.** NASA TM-84661, July 1983, 48 pp.

N83-29273#

This publication, containing 206 entries, supersedes an earlier bibliography, NASA TM-80225 (April 1980). Citations for 18 documents have been added in this updated version. Most of the additions report results of recent studies aimed at increasing the research capabilities of magnetic suspension and balance systems, e.g., increasing force and torque capability, increasing angle of attack capability, and increasing overall system reliability. Some of the additions address the problem of scaling from the relatively small size of existing systems to much larger sizes. The purpose of this bibliography is to provide an up-to-date list of publications that might be helpful to persons interested in magnetic suspension and balance systems for use in wind tunnels.

*Kentron International, Inc., Hampton, VA 23665
**NASA, Langley Research Center, Hampton, VA 23665

175 *Ericsson, L.E.; and *Reding, J.P.: **Practical Solutions to Simulation Difficulties in Subscale Wind Tunnel Tests.** Presented at the Fluid Dynamics Symposium, Cesme, Turkey, Sept. 26–29, 1983. Paper No. 16 in "Wind Tunnels and Testing Techniques," AGARD CP-348, 8 pp., 67 refs.

Reynolds number scaling and support interference are the two main problems encountered in wind tunnel tests with subscale models. In the past, when the designer was striving to maintain attached flow over the vehicle, neither problem was very difficult to solve. The use of boundary layer trips often could solve the scaling problem and only the clumsiest model support design would cause any interference beyond the easily corrected base drag effect. However, when separated flow effects dominate the aerodynamics, as often is the case for present day high performance aircraft and missiles, both problems become formidable. The paper describes practical means through which the test engineer can resolve these difficulties.

*Lockheed Missiles & Space Co., Inc., Sunnyvale, CA 94086

176 *Saiz, M.; and **Quémard, C.: **Airbus A 310 — Essais dans la Soufflerie F1 de l' ONERA. Comparaison Vol-Soufflerie** (Tests in the F1 ONERA Wind Tunnel and Comparison with Flight).

Presented at the Fluid Dynamics Symposium, Cesme, Turkey, Sept. 26–29, 1983. Paper No. 22 in "Wind Tunnels and Testing Techniques," AGARD CP-348, 50 pp.

A theoretical computation by a panel method is used to calculate the flow field in the presence of supports without a model. The variations of the pressure on the test section axis and the induced angle of attack are given. These computations are used to establish the mean induced angle of attack and the relative correction for kinetic pressure. These results have been confirmed by experiments done in the wind tunnel without a model, measurements being taken with a long pressure probe. The verification consists of specific tests which establish the global influence of the supports on the forces applied to the model. To further define this influence, dummy supports were used. Wall interference is computed. This paper contains comparisons of three large support system types in the same tunnel and supporting the same configurations.

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16. Abstract

The present supplement to NASA TM-81909 continues the numbering used in the original bibliography, and consists of 33 citations which focus specifically upon support interference problems which are thought to be directly solvable by magnetic suspension and balance systems (MSBS). Included are some recent publications as well as several works inadvertently omitted from the earlier, more comprehensive compilation.

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